Order parameter in laminar-turbulent patterns

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Over a century, and thousands of articles, after Reynolds' description of the transition to turbulence in pipe flow, a predictive theory of transition is still unavailable. One of the most intriguing phenomena observed near transition is the coexistence of well-defined and long-lived laminar and turbulent regions, first observed in counter-rotating Taylor-Couette flow in the 1960s [1]. In the 2000s, Prigent & Dauchot [2] showed that these coexisting regions were part of a regular pattern of stripes, whose wavelength and orientation are Reynolds-number-dependent and reproducible. Analogous phenomena have been observed experimentally [2] and numerically [3] in plane Couette flow, in stator-rotor experiments (the flow between a stationary and a rotating disk) [4], in plane Poiseuille simulations [5], and, most recently, in simulations of pipe flow [6].

We analyze these flows as wave patterns, measuring their strength by the instantaneous 1D Fourier component a corresponding to their wavenumber and phase. Since the flows are stationary only in a statistical sense, we treat a as a random variable and construct its probability distribution function (pdf). Timeseries and pdfs for a from simulations of plane Couette flow are shown below. Three regimes can be distinguished. For $Re \gtrsim 420$, the turbulence is *uniform*, extending over the entire domain; the corresponding pdf has its maximum at $a = 0$. For $400 \lesssim Re \lesssim 420$, the pattern is *intermittent*, appearing and disappearing erratically; the corresponding pdf is neither maximal nor zero at $a = 0$. For $290 \lesssim Re \lesssim 400$, a statistically steady *turbulent-laminar pattern* is present; the corresponding pdf is zero at $a = 0$.

References

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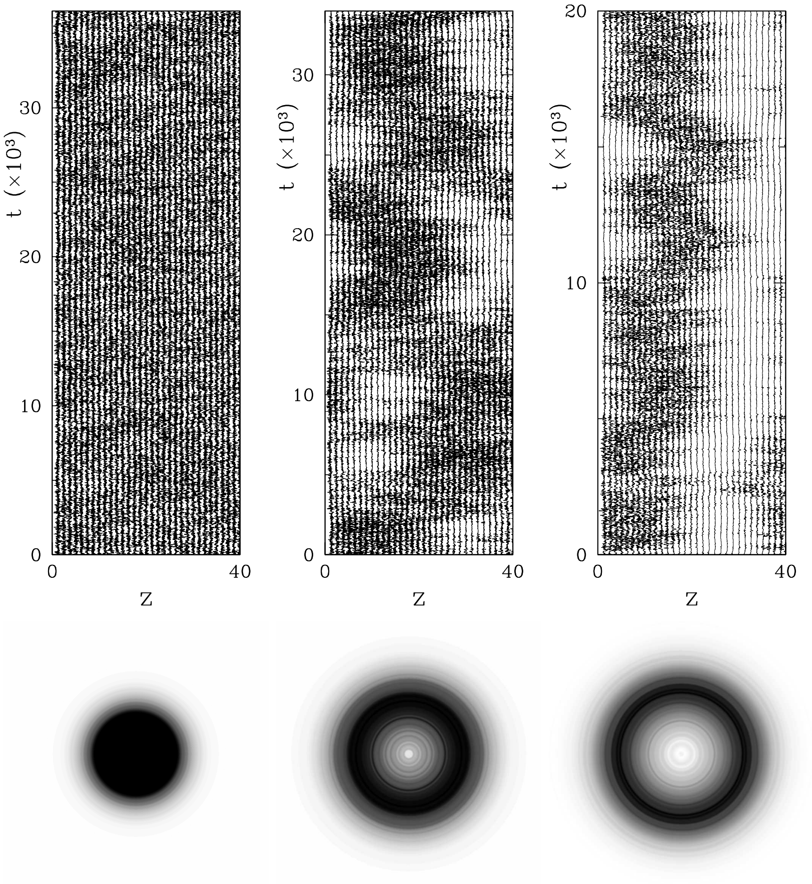

Fig. 1. Above: timeseries at $Re = 500$ (uniform turbulence), 410 (intermittent), 350 (turbulent-laminar pattern). Below: pdfs of Fourier component a.

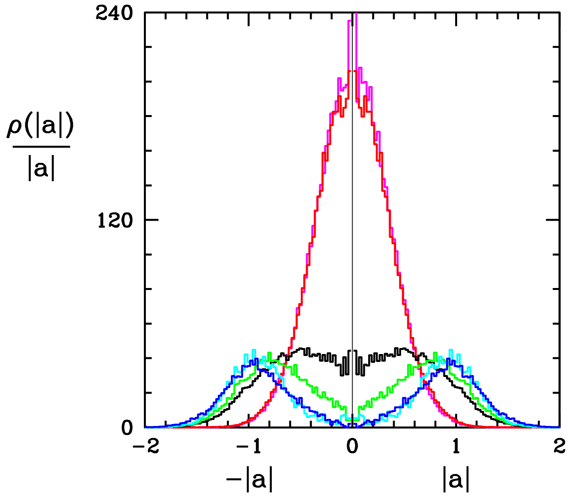

Fig. 2. Probability distribution function for $|a|$ for $Re = 580, 520, 420, 400, 350, 330$, in order of decreasing value at $|a| = 0$.